GEM 2007 Student Tutorial

M-I Coupling

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Outline

- Magnetospheric currents
- Field-Aligned Currents (FACs)
  - R1/R2, mantle (cusp) currents, SCW
- Observation – FAST
- Alfvén waves
- Examples – ground and satellite observations
What is M-I Coupling?

- Magnetosphere and ionosphere are closely linked together via magnetic field lines.
- Magnetospheric *electric fields* map down to the ionosphere, creating, e.g., plasma convection (*E* × *B* plasma drift), frictional heating and plasma instabilities.
- Auroral particle precipitation ionizes the high latitude atmosphere.
- Some of the cold ionospheric electrons and ions evaporate into the plasmasphere, plasma sheet and tail lobes: plasma outflow.
Magnetospheric Currents

- Magnetopause current
- Tail current
- Neutral sheet current
- Ring current
- Auroral electrojets

**Field-aligned currents (FACs)**

- Electric currents are very important for the dynamics of the Earth’s plasma environment. They transport charge, mass, momentum and energy.
- The currents create magnetic fields, which may severely alter or distort any pre-existing fields.
Field-Aligned Currents (FACs)

- The field-aligned currents (called “Birkeland currents”) connect the magnetospheric current systems in the magnetosphere to those flowing in the polar ionosphere.

- The FACs are mainly carried by electrons and are essential for the exchange of energy and momentum between these regions.

- The ionosphere is itself a generator of current and the same principles apply; field-aligned currents flow into and out of the magnetosphere.

- Temporal changes are transmitted between the regions by Alfven waves.
FACs

1. **Region 1/2 currents**: Expands to lower latitudes with increasing activity; current increase as the electric field associated with the solar wind/IMF increases.
   - *Region 1 currents* – Near the poleward edge of the auroral zone, down into the ionosphere on the dawnside, up from the ionosphere on the duskside. Driver of ionospheric convection.
   - *Region 2 currents* – Equatorward part of the auroral zone. Flow up from the ionosphere on the dawnside, down into the ionosphere on the duskside.
FACs

2. Mantle(or called cusp currents)/NBZ (northward Bz) currents

- Poleward of the R1 near local noon, Current directions opposite to the adjacent R1 currents.
- Strong IMF By effect: for By > 0 predominantly upward in the northern hemisphere and downward in the southern, and the other way round for By < 0
- Strong IMF Bz effect
- Bz < 0: mantle currents - well localized, weak currents
- Bz > 0: NBZ currents - expand and become as strong as the weakened R1/R2 currents

[Heelis, 2005]
FACs

3. Substorm current wedge

[Heelis, 2005]
Cusp Current

- The signature of the dayside interaction of the interplanetary magnetic field with the geomagnetic field.
- A variation in the configuration of the cusp currents is strongly dependent on IMF By.
- Cusp currents decrease the C-F current at high latitudes where it is replaced by the Region 1 current closure path.

[Heelis, 2005]
Substorm Current Wedge

- Plasma sheet thinning can be associated with a diversion of some portion of the neutral sheet current through the ionosphere.
- This process occurs during a “magnetic substorm” and the current loop is called a “substorm current wedge”.

[Heelis, 2005]
Recent Observations from FAST Satellite

- 30 seconds of data from the FAST (Fast Auroral SnapshoT) satellite.
- Top 4 panels give energy and pitch angle of electrons and ions (180 degrees is upward).
- Next is perpendicular electric field. Strong perpendicular fields always are seen in auroral zone.

[McFadden et al., 1998]
Field-Aligned Acceleration on FAST Satellite

- Strong low energy electron fluxes (red regions at bottom of panel 4) which are field-aligned (0 degree pitch angle in panel 5). [Chaston et al., 1999].

- These particle fluxes are associated with strong Alfvén waves (top 3 panels: electric field, magnetic field, and Poynting flux), suggesting wave acceleration.
Instruments

- Electric field measurements – intensity (V/m)
- Magnetic field measurements – intensity (nT or nT/s)
- Particle measurements - energy (eV), pitch angle dist., etc.
- Imager (visible, X-ray, UV, IR...)

STOP
How are Alfvén waves produced?

- Linear mode conversion
- Reconnection at distant neutral line
- Bursty Bulk Flows (BBF or fast flows) at substorm onset
- Time-dependent transmission of electromagnetic energy is accomplished by Alfvén waves.
- Strong Alfvénic Poynting flux observed at plasma sheet boundary: leads to field-aligned acceleration of electrons [Lysak, 2003].
• **Observation #1:** Simultaneous observations of Pi1B pulsations (ULF broadband irregular bursts at 0.025 ~ 1 Hz) using ground-based and satellite-borne magnetometers (GOES and FAST) at substorm onset (magnetic reconnection) on Jan. 12, 1997 07:28 UT.
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POLAR VIS images, showing initial brightening between 7:25 and 7:30, compares well with other estimates of 7:28
Observation #2: Simultaneous observations of Pi1B pulsations using ground-based and satellite-borne magnetometer (Cluster and Polar) at substorm onset (magnetic reconnection) on Sep. 20, 2003 02:00 UT.

- Polar (upper two panels, right) and Cluster (3rd and 4th panels, right) observations of Pi1B pulsations at substorm onset (magnetic reconnection). The bottom panel shows Cluster measures the ion flow propagating tailward (fast flows or bursty bulky flows: BBF).
Reconnection model – possible relation to Pi1B generation

Animation showing how magnetic field lines of opposite direction break and reconnect. Such reconnection events in space create jets of high-speed particles.

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Observation of Pi1Bs

Overview/Scenario

- Pi1B signatures, which are observed with burst bulky flows (fast flows) by Cluster (~ 20 RE) at substorm onset (reconnection), are seen as compressional waves at geosynchronous orbit by GOES. Then, as the flows propagate earthward, they become increasingly parallel to the background field, eventually undergoing a mode conversion to Alfven waves, which propagate parallel to the background field. FAST satellite observes the Alfven waves and auroras were observed on the ground.
GEM 2007 Focus Group - MIC

- FG6 – MICET (MIC Electrodynamics and Transport): MIC gap region, cross-latitude coupling (Mon)
- FG7 – Global MIC: Dayside Global Ionospheric Electrodynamics, Reconnection (Tue)
- FG10 – Diffuse Aurora (Wed)
- And MIC tutorials (Mon, Thu)
A polar bear shown up at Polish Polar Station, Hornsund, Svalbard. Courtesy of Piotr Modzel.
Field-Aligned Currents vs. Alfvén Waves

- Field-aligned current is often quoted as energy source for aurora.
- But, the kinetic energy of electrons is negligible: Poynting flux associated with FAC is responsible.
- FAC closed by conductivity in ionosphere; electric and magnetic fields related by

\[ \frac{A_y}{A_x} = \frac{B_y}{B_x} = \frac{\mu_0 \rho}{\Sigma_\rho} \]

\( \Sigma_\rho \) is usually > 1 mho, so ratio is less than 800 km/s

- Alfvén waves have a similar electric and magnetic field signature, but for these waves

\[ \frac{E_x}{B_y} = V_A = \frac{B_0}{\sqrt{\mu_0 \rho}} \]

\( V_A \) is usually much greater than 1000 km/s, can be up to speed of light

- Thus, large E/B ratios indicate Alfvén waves, smaller ratios static currents

- Oversimplified picture! Wave reflections, parallel electric fields, kinetic effects all affect this ratio.
Alfvén Waves on Polar Map to Aurora and Accelerate Electrons

Left: Ultra-violet image of aurora taken from Polar satellite. Cross indicates footpoint of field line of Polar (Wygant et al., 2000)

Right: Electron distribution function measured on Polar. Horizontal direction is direction of magnetic field. Scale is ±40,000 km/s is both directions (Wygant et al., 2002)